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Abstract: In this paper we study the manuscript tradition of Petrus Alfonsi's Dialogus contra Iudaeos, written around AD 1110. This text was widely disseminated in the Middle Ages, especially during the century after its composition; there are over sixty complete manuscripts known. In order to group them we calculate a distance matrix from standardised text strings transcribed from the manuscripts. From this, tree graphs can be generated easily and quickly with the aid of software developed for biological phylogeny. The resulting tree graph can be iteratively improved by modifying the distance matrix using a number of methods, partly fully algorithmic, partly relying on philological decisions. We are thus able to divide the tradition into some ten main groups.

DOI: https://doi.org/10.1484/J.RHT.5.101260

TOWARDS GENERATING A STEMMA OF COMPLICATED MANUSCRIPT TRADITIONS: PETRUS ALFONSI'S *DIALOGUS*

Summary

In this paper we study the manuscript tradition of Petrus Alfonsi's *Dialogus contra Iudaeos,* written around AD 1110. This text was widely disseminated in the Middle Ages, especially during the century after its composition; there are over sixty complete manuscripts known. In order to group them we calculate a distance matrix from standardised text strings transcribed from the manuscripts. From this, tree graphs can be generated easily and quickly with the aid of software developed for biological phylogeny. The resulting tree graph can be iteratively improved by modifying the distance matrix using a number of methods, partly fully algorithmic, partly relying on philological decisions. We are thus able to divide the tradition into some ten main groups.

Résumé

Dans cet article, nous étudions la tradition manuscrite du *Dialogus contra Iudaeos* de Petrus Alfonsi, écrit aux alentours de l'an 1110. Ce texte fut largement recopié durant le Moyen Âge, surtout pendant le siècle suivant sa composition ; plus de soixante manuscrits complets du texte sont connus. Dans le but de les grouper nous calculons une matrice de distance d'un extrait de texte standardisé transcrit des manuscrits. Partant de cela, des dendrogrammes peuvent être facilement produits à l'aide de logiciels développés pour la phylogénétique en biologie. Le dendrogramme résultant peut être amélioré itérativement en modifiant la matrice de distance à l'aide de différentes méthodes: certaines d'entre elles sont algorithmiques, tandis que d'autres s'appuient sur des jugements philologiques. Nous sommes ainsi capables de diviser les manuscrits en une dizaine de groupes.

Introduction

In the last decade or so various attempts have been made to use phylogeny software from modern molecular biology to generate stemmata of manuscript traditions.[1] Molecular biologists have developed such software in order to infer the relatedness of species or populations by comparing parts of their DNA sequences. The most common methods are based on the calculation of a distance matrix[2] and then constructing a tree graph[3] from the matrix. The applicability of these methods to

1 First approaches, however, date back to the 1970s, e.g. P. Tombeur, J.-C. Boulanger, J. Schumacher, *Génération automatique d'un stemma codicum,* in *La pratique des ordinateurs dans la critique des textes, Colloque international du CNRS, Paris, 29-31 mars 1978,* Paris, 1979, p. 163-183. In the last few years there were some significant publications on testing different methods from Leuven, cf. especially the contributions in C. Macé, P. Baret, A. Bozzi, L. Cignoni (eds.), *The evolution of texts: Confronting stemmatological and genetical methods, Proceedings of the International Workshop held in Louvain-la-Neuve on September 1-2, 2004,* Linguistica Computazionale, vols. XXIV-XXV, Pisa-Roma, 2006. Further cf. M. Spencer, E. A. Davidson, A. C. Barbrook, C. J. Howe, *Phylogenetics of artificial manuscripts,* in *Journal of Theoretical Biology,* CCXXVII/4 (2004), p. 503-511, and M. Spencer, C. J. Howe, *Estimating distances between manuscripts based on copying errors,* in *Literary and Linguistic Computing,* XVI (2001), p. 467-484, and L. R. Mooney, A. C. Barbrook, C. J. Howe, M. Spencer, *Stemmatic analysis of Lydgate's 'Kings of England': a test case for the application of software developed for evolutionary biology to manuscript stemmatics,* in *Revue d'histoire des textes*, XXXI (2001), p. 202-240.

2 A *distance matrix* is a table that contains all the distances *d* (in some defined metric) between any pair of items (a,b). As the distance *d*(a,b) must by definition be equal to *d*(b,a), the matrix is symmetrical; and as any element must be at distance zero from itself (*d*(a,a)=0 for all a), the full information is contained in the lower triangle matrix.

3 A *tree* is a a connected graph in which any two nodes (the species in this case) are connected by exactly one path

manuscript traditions is based on the parallelism between DNA samples (sequences of nucleotide base pairs) and natural language texts (sequences of letters of the alphabet).[4]

In this article we will study the case of a medieval Latin text. Our algorithms construct a distance matrix out of text samples which can then be fitted to tree form. Our contribution is part of a larger project presently under way at the University of Zurich, in which Carmen Cardelle de Hartmann plans to edit Petrus Alfonsi's *Dialogus* (more fully *Dialogus contra Iudaeos*)[5] in a historical-critical manner for the first time, and to study its sources in depth. The present study of the mss will provide a necessary basis for such a new edition of the text. For this project our main goal is to group the more than 60 complete mss of the texts. We base our analysis primarily on a text sample of some 500 words transcribed from 51 mss. To assess our results, on the one hand we apply our algorithmic method to an artificial manuscript tradition (for which the "true" stemma is known), and on the other hand we compare our solution for the (unknown) stemma of the *Dialogus* tradition to a philological evaluation.

Petrus Alfonsi's *Dialogus*

Petrus Alfonsi[6] was a Jew who converted to Christianity on St. Peter's Day (June 29) 1106 in Huesca, which had been taken from the Muslims by Peter I of Aragón ten years before, under King Alfonso I of Aragón.[7] In honour of the day and of his royal godfather he changed his name from Moses to Petrus Alfonsi or Alfonsus.[8] Unfortunately this is the only precise date we have about our author. He had probably grown up in al-Andalus (Islamic Spain) and studied Arabic and Hebrew in depth. After his conversion he spent time in Northern France and England. Among his pupils in England was Walcher of Malvern.[9] His two major works are the *Disciplina Clericalis* and our *Dialogus*. In his œuvre Petrus brought for the first time reliable information about the Qur'an, Islam in general, Arabic sciences and contemporary Judaism to Latin readers and he quickly became an authority on Islam and Judaism in the Latin-speaking world. As a consequence his works are extant in a large number of manuscript copies, many of which date still from the twelfth century. The nature of the manuscript tradition, rapidly divergent within a century of the composition of the original text, accounts for a complicated stemma with a large number of manuscript groups.

Unfortunately, it is not clear whether Petrus wrote his *Dialogus* right after his conversion in 1106. Indeed, judging from his addressing Alfonso as *imperator* we may conclude that the text was written between 1109 and 1114 when Alfonso rightfully bore that title.[10] We have found 59

(along *edges* of variable length). Nodes that are connected with only one edge are called *leaves* of the tree. In our trees every node that is not a leave connects exactly three edges. A tree is called *rooted* if exactly one node is designated as the *root*. In a rooted tree the edges are oriented (as pointing away from the root). A tree can be turned into a *stemma codicum* by rooting it.

4 Cf. C. Macé, Ph. Baret, *Why phylogenetic methods work: the theory of evolution and textual criticism,* in *The Evolution of Texts* (*op. cit.*), p. 89-108.

5 The *Dialogus* is edited in Migne's *Patrologia Latina* (PL 157, cols. 527-672) following the 1536 *editio princeps* (Gy in table 1) which in turn is based on a lost ms., apart from this there is a semi-critical edition by K.-D. Mieth, *Der Dialog des Petrus Alfonsi. Seine Überlieferung im Druck und in den Handschriften. Textedition,* Dissertation, FU Berlin, 1982 [henceforth "Mieth"]. His edition is based on four mss (B1, B2, P1, P2) and the *editio princeps* (Gy); in his text he usually follows B1. An English translation of the *Dialogus* is available in I. M. Resnick, *Petrus Alfonsi, Dialogue against the Jews,* The Fathers of the Church, Medieval Continuation vol. 8, Washington D.C., 2006.

6 Fundamental for Petrus is J. Tolan, *Petrus Alfonsi and his medieval readers,* University Press of Florida, 1993, for an assessement of Petrus' works, cf. Ch. Burnett, *The works of Petrus Alfonsi: Questions of authenticity,* in *Medium aevum* 66 (1997), p. 42-79. For one of current research cf. C. Cardelle de Hartmann, *Pedro Alfonso y su Dialogus: estado de la cuestión,* in *Actas del V congreso internacional de latín medieval hispánico,* Barcelona 7-10. Sept. 2009 [in print].

7 Called *el Batallador* for his military prowess; he reigned from 1104 to his death in 1134.

8 Either in genitive or nominative, depending on the source. In fact the mss mostly write the name *Alfunsus*.

9 Cf. the *Sententia Petri Ebrei, cognomento Anphus, quam dominus Walcherus prior Malvernensis ecclesie in latinam transtulit linguam,* short *De dracone,* about the prediction of eclipses. The text dates from 1120.

10 He acquired and subsequently lost it by his marriage to Urraca of León. From the mentioning of 1040 years (cf.

complete[11] manuscripts of the text[12] and three more that contain substantial parts. The oldest of these (P3) was written still in the first quarter of the 12th century,[13] leaving a gap of at best little more than a decade between this oldest ms. and the original text of Alfonsi's.[14] However, certain readings and the fact that P4 is a contaminated copy of P3 (i.e. contaminated by another, unknown ms.) make clear that this ms. is not the archetype itself, which is, as in most cases, lost. Compare table 1 for basic information on all the mss we used; this includes just the more or less complete ones actually taken into account in our calculations, the approximately 30 more short excerpts or redactions of the text are not included. For easy reference we have already included the groups of manuscripts we will determine below.

Manuscript[15]	**sig.**[16]	**gr.**[17]	**ff.**	**age**[18]	**provenance**[19] **and comments**
Paris, Bibliothèque de l'Arsenal 769	A1	∅	158r-179r	XIII 1/4	St. Victor (Paris) – incomplete (*tituli* 1-5 of 12)
Paris, Bibliothèque de l'Arsenal 941	A2	A	53r-98v	XII / XIII	Cluniacensian monastery St. Martin des Champs (Paris)
Paris, Bibliothèque de l'Arsenal 553	A3	A	20r-98v	1451	Written by Thomas Poyet, later in Collège de Navarre
Antwerp, Museum Plantin Moretus lat. 2 / M 15.3	An	B	77v-124v	XII 3/3	Cistercian abbey Vaucelles
Arras, Bibliothèque municipale 1016 (ex 432)	Ar	B	1r-41r	XII 2/3 or 2/4	Benedictine abbey St. Vaast (Arras) – pages missing
Augsburg, Universitätsbibliothek Cod. II. 1 fol. 41	Au	∅	157r-214v	XV	substantially altered text
Berlin, Staatsbibliothek zu Berlin – Preußischer Kulturbesitz, Phillips 1721	B1	F	1r-132v	XII 3/5 or 4/5	prob. French, later in Collège des Jésuites de Clermont
Berlin, Staatsbibliothek zu Berlin – Preußischer Kulturbesitz, Hamilton 21	B2	E'	1r-42v	14th	Benedictine abbey San Giorgio Maggiore (Venice)
Bern, Burgerbibliothek cod. 188	Be1	H	35r-89r	XII 3/3	Celestinian abbey Sancta Maria (Metz)
Bern, Burgerbibliothek cod. 111	Be2	H	169r-217v	XII 4/4	copy of Be1, also from there

Mieth 33,35) since the latest Jewish *captivitas* (after the destruction of the Second Temple) some scholars conclude that the work was written in 1109 or 1110. More about dating in Cardelle de Hartmann (*op. cit.*).

11 Some of them lack some pages due to loss or damage during the transmission, unfortunately especially two of the oldest and most important ones (P3 and Ar).

12 Two more were lost when the library of Turin burned down in 1904 and one in the second World War.

13 All mss within a century or so of the original have been dated anew according to paleographic criteria by Carmen Cardelle de Hartmann for this project. Her new datings are contained in table 1.

14 The next oldest mss are some decades younger: P4 (2/4), Ar (2/3 or even 2/4), P2 (3/5) and B1 (3/5 or 4/5). For the notation, cf. note 18.

15 For easy reference from our plots the mss are given in alphabetical order of their sigla. We include in this list three mss that were destroyed and one we could not obtain copies from.

16 The abbreviations are mostly based on Tolan (*op. cit.*).

17 The symbol ∅ denotes mss that do not fit into any of the groups. The asterisk (*) denotes probable cases of contamination.

18 All dating in Roman numbers was newly done paleographically by Carmen Cardelle de Hartmann for the current Petrus Alfonsi Project at the University of Zurich. In order to save space the dating system gives the possible interval by a "fraction" number. 1/2, e.g., means first half of the century given by the Roman number. Century dates in Arabic numbers are taken from the extant manuscript catalogues. Precise numbers are given for dated mss.

19 Note that by provenance we mean the earliest traceable location. Not in all cases the ms. will have been written there. The information, unless otherwise stated, is from the relevant catalogues, from Santiago-Otero (in M. J. Lacarra, *Pedro Alfonso,* Zaragoza, 1991), Tolan (*op. cit.*), with detailed information about other works in the mss, and from Mieth (*op. cit.*); in all of these further information on most of the sources can be found.

Burgo de Osma, Biblioteca Capitular 35 (28)	Bo	β	7r-139r	1380	Spanish
Brugge, Bibliotheek van het Grootseminarie ms. 26/91	Br	H	1-104v	XIII 2/2	Cistercian abbey Ten Duinen (Koksijde)
Cambrai, Bibliothèque municipale 166 (161)	Ca	A’	154r-197r	late 14th	cathedral library Cambrai
Cambridge, Corpus Christi College 309	Cc	C	37r-78v	XIII 1/3	Benedictine abbey St. Mary (York)
Cambridge, Pembroke College 244	Cp	E	49v-91v	14th	Pembroke College, Cambridge
Cracow, Biblioteka Jagiellońska 1197	Cr	G	23r-118v	15th	Austria
Chartres, Bibliothèque de la Cathédrale 127 (130)	Ct			12th	Benedictine abbey Saint Père, Chartres – destroyed in the 2nd World War
Dijon, Bibliothèque municipale 228 (ex 190)	D1	F	2r-92r	XII 4/4	Cîteaux
Dijon, Bibliothèque municipale 230 (ex 192)	D2	F’	2r-101v	XIII 1/2	Cîteaux, copy of D1
Douai, Bibliothèque municipale 199	Do	B	95r-158v	XII 3/4	Benedictine abbey Anchin (Douai)
Cambridge, Fitzwilliam Museum, McClean Collection 120	Fi	A’	1r-129v	XII 3/3	English
Göttingen, Niedersächische Staats- und Universitätsbibliothek, Luneb. 12	Go	B	1-66v	15th	given to Benedictine abbey Lüneburg still in the 15th century
Coloniae apud Ioannem Gymnicum: *Petri Alphunsi ex Iudaeo Christiani Dialogi*	Gy	B	-	1536	*editio princeps* based on a lost ms. *e Bibliotheca Corbenensi* (sic)[20] – reprinted with some mistakes in Migne
Cambridge Mass., Harvard College Library, MS Judaica 16	Ha	B	1r-182r	XV 2/4	Germany[21]
Hereford, Cathedral Library P. 2 IV	He	E	1r-108v	XII 3/3	English, prob. from Hereford Cathedral
Cambridge, St. John’s College, E. 4 (James 107)	J1	A	117r-180v	XII 3/3	provenance unknown
Cambridge, St. John’s College, D. 11 (James 18)	J2	C	1r-64v	XII / XIII	Premonstratensian monastery Beauchief (Derbyshire)
Klosterneuburg, Stiftsbibliothek 352	Kn1	∅	101r-146v	14th	French
Klosterneuburg, Stiftsbibliothek 826	Kn2	D	87r-207r	1391	Augustine Canons at Neuburg
Kremsmünster, Stiftsbibliothek 82	Kr	G	1r-68v	15th	German, same scribe as Me?
London, British Library, Harley 3861	L2	E*	1ra-93vb	XII 3/3	English[22]
London, British Library, Royal 15 C II	L3	E*	116ra-177rb	early 13th	Salisbury cathedral
London, British Library, Additional Ms 15404	L4	F'	31r-144r	XIII 2/2	Cistercian abbey Camberon (Belgium)
Leiden, Bibliotheek der Rijksuniversiteit, Scaliger 42	Ld	A	1r-104v	XIII	provenance unknown
Liège, Bibliothèque Générale de	Li	∅	139r-198v	15th	Canons Regular (Crosiers) at Huy

20 This could mean Corbie or Corvey. Our grouping of the text with mostly German mss suggests that Corvey in North Rhine-Westphalia is meant. Quotation from Mieth p. XIV.

21 According to Santiago-Otero (*op. cit.* p. 20). The dating is based on German origin, otherwise the ms. might be older (XIV).

22 According to paleographic evidence (Carmen Cardelle de Hartmann); very similar to He.

l'Université 360 (cat. 351)					(close to Liège)
Lisbon, Biblioteca Nacional, Alcobaça 148 (CCXLI)	Ls	F	1r-123r	XIII 1/4[23]	Cistercian abbey Santa Maria de Alcobaça
Melk, Stiftsbibliothek 1059	Me	G	p. 25-160	1414	Benedictine abbey Melk, scribe Nicholas of Newberg, cf. Kr
Munich, Bayerische Staatsbibliothek Clm 28225	Mu	D	81r-168r	XIII 1/2	Cistercian abbey Kaisheim
Oxford, Bodleian Library, Bodley 801	Ob	E	206r-268v	15th	"*ex dono Joannis Blacman*"
Oxford, Bodleian Library, Laud. Misc. 356	Ol	P	1r-120r	15th	French, copy of P2 (Tolan)
Oxford, Bodleian Library, Rawlinson C. 322	Or	E	1r-60v	14th	English
Paris, Bibliothèque nationale de France lat. 10624	P1	A	63v-171r	XII 3/3	provenance unknown
Paris, Bibliothèque nationale de France lat. 10722	P2	P	3r-76v	XII 3/5	Anglo-Norman or French?
Paris, Bibliothèque nationale de France lat. 5080	P3	A	145r-205r	XII 1/4	Benedictine abbey Fécamp
Paris, Bibliothèque nationale de France lat. 14069	P4	A/ P*	49r-113v	XII 2/3	Benedictine abbey St. Germain des Prés – contaminated copy of P3[24]
Paris, Bibliothèque nationale de France lat. 15009	P5	A'	205r-255r	XII 3/3	St. Victor (Paris)
Paris, Bibliothèque nationale de France lat. 3359a	P6	B/E*	2r-61v	XIII/ XIV	Benedictine abbey of St. Jean de Laon – incomplete (*tituli* 1-5 of 12)
Paris, Bibliothèque nationale de France lat. 16523	P7	F	2r-61r	14th	provenance unknown
Paris, Bibliothèque Mazarine 980	Pm	β	93r-129v	XIV 1/2	Benedictine abbey St. Denis (Paris) since at least the 17th c. – incomplete (*tituli* 1-10 of 12)
Porto, Biblioteca Pública Municipal do Porto 34 (43)	Po	F	1r-73r	XIII 1/4	Canons Regular at Santa Cruz de Coimbra, cf. Ls
Prague, Archiv Pražského hradu C.XCV	Pr1	E'?	14r-37v	14th	provenance unknown
Prague, Archiv Pražského hradu N.XLI	Pr3	G	56r-110v	early 15th	Bohemia
Salamanca, Biblioteca Universitaria 2579	Sa	T	4r-130v	16th	Spanish, transcribed by Juan de Paria for printing
Santo Domingo de la Calzada, Biblioteca Capitular 2	Sd	E	96r-141r	XIII 1/2	Spanish, since 1568 in the Franciscan monastery San Francisco (Santo Domingo)
Troyes, Bibliothèque municipale 509	T1	F'	1r-57v	XIII 1/2	Clairvaux
Troyes, Bibliothèque municipale 1720	T2	T	1r-68v	XIII 1/2	provenance unknown
Tarragona, Biblioteca provincial, Códice Misceláneo 55 (olim 126)	Ta	F	109r-215v	XIII	writing not Spanish; was in the Cistercian abbey Santes Creus (Tarragona)

23 We thank Aires A. Nascimento (Lisbon) for this dating and the one of Po which is likely to be a little younger and thus a direct copy of Ls.

24 Tolan (p. 194) considers contamination by P5. But this ms. is younger than P4 and the contamination may well be the other direction.

Tortosa, Biblioteca de la Catedral 15	To	F	1r-115r	XIII 2/2	provenance unknown
Turin, Biblioteca Nazionale Codex E. I. 43	Tu1		13r-31r	15th	both ms. were destroyed in the fire of 1904 – for both the provenance was unknown
Turin, Biblioteca Nazionale Codex D. I. 16	Tu2		?	15th	
Utrecht, Bibliotheek der Rijksuniversiteit 257 (eccl. 195)	Ut	T?	156r-205v	1466	provenance unknown
Vatican, Biblioteca Apostolica Vaticana Vat. lat. 988	V1	F	80r-155v	1455	written in Leuven – pages missing
Vatican, Biblioteca Apostolica Vaticana Pal. lat. 425	V2	B	1r-72v	1392	the Pal. lat codices stem from Heidelberg
Vatican, Biblioteca Apostolica Vaticana Vat. lat. 1294[25]	V3		37v-246v	?	?
Vienna, Österreichische Nationalbibliothek 1623	Wi	D	1r-83r	early XIV	Carthusian abbey Mauerbach
Zurich, Zentralbibliothek MS C 125	Zu	H	1r-88r	XIII 1/2	Cistercian abbey Aldersbach

Table 1: List of the manuscripts of the main redaction of the *Dialogus* used in our simulations, including three lost ones (Ct, Tu1, Tu2) and one we could not obtain copies from (V3).

Table 2 summarises what we know about the provenance of our mss. We see that the transmission of our text throughout Europe largely happened among Benedictine and Cistercian monasteries and mainly in France (and Belgium) and to a lesser degree in Germany, England and on the Iberian Peninsula.

	Benedictines	*Cistercians*	*Canons*	*others / unknown*	*total*
France / Belgium	Ar, Ct, Do, P3, P4?, P6, Pm? Celestinians: Be1, Be2 Cluniacensians: A2	An, Br, D1, D2, L4, T1	A1, P5, Li	A3?, B1, Ca, Kn1, Ol, P2?, V1	26
Germany / Austria	Go, Me	Mu, Zu	Kn2	Cr, Gy?, Ha, Kr, Pr3, V2 Carthusians: Wi	12
England	Cc			Praemonstratensians: J2 Cp, Fi, He, L2, L3, Ob?, Or	9
Iberia		Ls, Ta	Po	Bo, Sa, Sd	6
Italy	B2				1
unknown				Au, J1, Ld, P1, P7, Pr1, T2, To, Tu1, Tu2, Ut, V3	12
total	14	10	5	37	66

Table 2: Summary of mss provenance listed in table 1, by monastic Order.

A critical edition for Alfonsi's other major work, the *Disciplina clericalis* was published by Hilka and Söderhjelm a century ago.[26] We do not know the work's date of composition. The editors found 48 complete and 15 fragmentary mss, of which only one also contains the *Dialogus*.[27] As the

25 Contains our text according to Santiago-Otero (in Lacarra, *op. cit.*), p. 20. Unfortunately there is no catalogue for this ms. outside the Vatican and a reproduction can presently not be obtained due to the Vatican's library closure. So we could not use it in the present study.

26 A. Hilka, W. Söderhjelm, *Petri Alfonsi Disciplina clericalis. I. Lateinischer Text,* Helsingfors, 1911.

27 Tolan's Be3, kept in Bern, is one of the mss with an altered recension of the *Dialogus*. Therefore it is not contained in table 1.

Disciplina is a kind of *summa* of moral teachings and is thus intended for a rather different audience than our polemical dialogue, this is not very surprising. Many of its mss go back to the 12th century; nevertheless the editors were not able to produce a stemma: the text seems to have diversified too quickly in the first decades of its existence and has suffered contamination. They were, however, able to distinguish an older (better) recension (contained in 36 mss) and a younger one (in 12 mss). Among the older one, some clusters of two to four mss could be grouped. Consequently they based their edition on a single ms.[28] enriched by readings of some of the others. Karl Strecker[29] criticised the editors severely for their failure to group the textual tradition and thus using a single ms. as basis for the edition. He believed it would have been possible to reconstruct a text close to the author's. The traditions of the two works have many things in common. With Strecker we believe that also for the *Dialogus*, despite its complicated tradition, a text close to the author's can be regained.

Algorithms

Data Preparation

Our method is based on a text sample, excerpted from each ms. Obviously, the longer the excerpted text, the more reliable the result is going to be. As excerpting dozens of mss is labour intensive, the preparation of the sample is the bottleneck in terms of cost or effort. For the *Dialogus,* we chose a sample compiled from three different parts of the text; two from the beginning (sample 1: Mieth 1,10-29; sample 2: Mieth 3,14-39) and one at the very end of the text (sample 3: Mieth 143,15-23). The text at the end was not a very fortunate choice as it was missing in 6 (out of 62) mss.[30] Four more mss had other parts of the sample texts missing.[31] These ten mss were removed from the sample and especially dealt with at the end. After also removing the idiosyncratic Au we retained a total of 51 mss. Our text sample has an average length of 521 ± 10 words or 2943 ± 52 letters. By comparison, the artificial tradition of Baret et al., used to test our algorithm below, has a length of 977 ± 113 words or 4490 ± 590 letters (based on 13 mss). For the *Dialogus,* we found the 520 words excerpt to be on the lower limit of usability and have augmented it with some further data for the final stemma (see below and fig. 5).

Before comparing the excerpts of the individual mss, the text sample needs to be normalised in order to minimise the impact of trivial variation. This normalisation included (i) removing punctuation, (ii) collapsing letter case, (iii) collapsing *j* and *y* with *i,* and *v* with *u*, as well as (iv) the normalisation of common spelling variants in medieval Latin, such as *quicquid / quidquid, immo / imo*, *mihi / michi, archana / arcana* etc.*,* and (v) silent emendation of some obvious misspellings (e.g. *adhesserat* for *adheserat*). In addition, as the text is a dialogue, most manuscripts indicate the speaker (i.e. either "Petrus" or "Moyses" often as rubrics). Since this is done inconsistently, these indications have been ignored altogether. It should be noted that strictly speaking, this sort of normalisation already entails a philological judgement on which variations are significant (or which should be considered "errors" as opposed to trivial variants).

Distance matrix

The excerpted sample from each ms. will be compared to that of each other ms., introducing a notion of quantitative (numeric) "relatedness" or "distance" between text strings. For n mss, this amounts to $\frac{1}{2} \cdot n \cdot (n-1)$ comparisons, or in our case of $n=51$ to a total of 1275 distance calculations. Arranged in tabular form, these figures are the distance matrix of the tradition. The notion of

28 Oxford, Corpus Christi College 86 (14th century).

29 In a review in *Deutsche Literaturzeitung* 33 (1912), col. 862-865, online at www.archive.org, he criticised the editors strongly for their failure to group the textual tradition and thus using a single ms. as basis for the edition.

30 A1, J2, P3, P6, Pm, Sd. Thus among them the oldest ms. P3; fortunately it has a close relative in the complete Fi.

31 Ls (Mieth 1,10-19), Ar and Ol (Mieth 3,26-39) and V1 even the entire sample 2.

"distance" employed here is mathematically speaking a *metric* between text strings. In the most general case, such a metric would operate at the character level. We found it practical, however, both for philological reasons and for reasons of calculation cost, to consider metrics operating at the word level, i.e. we consider our excerpts as ordered lists of words. The selection of a good metric is the crucial step, determining the quality of the generated tree. By contrast Baret et al. in their artificial text tradition (discussed below, cf. note 38) used one metric, essentially a manual implementation of the "diff" metric, and focussed on comparing algorithms for generating tree graphs from the matrix.

The generation of the actual tree from the distance matrix is indeed a highly non-trivial problem,[32] but it is also one shared by phylogeny in general and thus not specific to our case. The cost of calculation of the optimal tree from the matrix[33] is super-exponential in the number of mss, but there are a number of common methods to approximate a near-optimal tree in use in biology. We used a standard weighted least squares approach, the Fitch-Margoliash method[34] as implemented in the PHYLIP package[35] with a calculation cost proportional to the square of the number of mss.

(i) simple word frequency metric

The most naïve and cost-efficient way of comparing two texts is by simply counting the number of occurrences of each word and then summing up the differences in these counts between the two texts. This amounts to ignoring word order and treating the texts as unordered "bags of words". We mention this simple metric for the sake of completeness. It is capable of generating a stemma which correctly identifies the main phylogenetic groupings in the *Dialogus*, of a quality not far short of the result of the much more calculation intensive "diff" method discussed below. Evidently it fails in cases where large portions of text were omitted or added to a ms. (in our case e.g. for Cc and Ca).

(ii) edit distance ("diff")

The problem of comparing two texts is known in computing as "edit distance", a notion of distance between two text strings expressed in the number of edits or basic operations necessary to transform one into the other. The exact value will depend on the number of possible basic operations taken into account. The edit distance reported by the algorithm should by conception correspond to the number of single mistakes made by a manuscript's scribe. The edit distance between any two text samples should therefore reflect the "number of mistakes" made by the sum of copyists connecting the two mss from which the samples were taken. In principle, such mistakes may consist in deletion, insertion or transposition of one or more words from the text. In practice, most file comparison software calculates edit distances by solving the so-called *longest common subsequence* problem. A standard implementation of this approach is the *diff* utility, developed for UNIX in the 1970s.[36]

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32 Cf. the attempt to define a metric in tree space for the purpose of an objective comparison of solutions generated from different algorithms presented by T. Roos, T. Heikkilä, *Evaluating methods for computer-assisted stemmatology using artificial benchmark data sets,* in *Literary and Linguistic Computing Advance Access* published March 14, 2009. Their metric is based on the "triples distance" introduced by D. E. Critchlow, D. K. Pearl, Ch. Qian, *The triples distance for rooted bifurcating phylogenetic trees,* in *Systematic Biology* 45(3) (1996), p. 323-334).

33 I.e. the best possible tree graph fitting the distance between two elements to the path length between the corresponding nodes.

34 W. M. Fitch, E. Margoliash, *Construction of phylogenetic trees,* in: *Science* 155 (1967), p. 279-84.

35 J. Felsenstein, *PHYLIP - Phylogeny Inference Package, version 3.68,* University of Washington, 2009, http://evolution.genetics.washington.edu/phylip.html.

36 Cf. J. W. Hunt and M. Douglas McIlroy, *An Algorithm for Differential File Comparison,* in *Computing Science Technical Report, Bell Laboratories* 41 (1976), p. 1-8 . The implementation we used was the Algorithm::Diff perl module (version 1.15), written by Ned Konz.

(iii) "diff" based metric weighing consecutive edits

The diff algorithm returns a list of lists, each sublist identifying a number of consecutive edits made to the text at a specific offset. As we decided to operate on words, an edit is either the deletion or the insertion of a word. One naïve metric derived from this would simply count the number of edits contained in the diff output, corresponding to the number of words that need to be changed (inserted or deleted) to transform each text into the other. In scribal reality, however, a single error may affect a number of consecutive words (e.g. omitting a line in the manuscript). Therefore it seems sensible to give a lower score to a number of edits on consecutive words than to the same number of edits at discrete positions in the text. We address this by introducing a parameter p, weighing a number of k consecutive edits as k^p. A choice of p=1 would thus give equal weight to each edit, while p=0 would count any number of consecutive edits as a single edit which would tend to put mss with substantial text loss unrealistically close to the archetype, and to one another. The tree shown in fig. 2 below is based on an intermediate choice of p=1/2, thus weighing a series of consecutive edits with the square root of its length. Variation of the parameter between realistic values of, say, 1/3 to 2/3, is a way of assessing the robustness of the result: groups that can be postulated with any certainty remain invariant, while mss of uncertain affiliation (such as B2, Kn1 or An and Do) will fluctuate within the tree.

(iv) "diff" metric refined to detect likely leitfehler

The preceding paragraph illustrates that what we should ideally look for in our metric is not a simple count of edits or "errors", but a figure to which each error contributes weighed by its severity or significance to the stemma. This is an emulation of the concept of *leitfehler*[37] or *error significativus* in classical stemmatology. Variant readings that are unlikely to occur independently and unlikely or impossible to be reverted by later scribes should be given much more weight than the rank-and-file of everyday copyist's mistakes. Examples of such errors unsuited for manuscript differentiation are trivial changes to Latin syntax (e.g. word transpositions) or indeed simple spelling mistakes, already addressed by our normalisation procedure above. The assessment of the distinction as a *leitfehler* of any given variant reading is, of course, a philological task that we cannot hope to automate. But we can improve our metric by automatically collecting a preselection of *leitfehler* candidates. These will be comparatively rare words which appear in some mss but not in others. Compiling such a list of candidates, we can then pair any two list items A and B, and divide our entire manuscript corpus into four groups based on the occurrence of A and B, viz. (A, B), (A, no B), (no A, B) and (no A, no B). This is illustrated in table 3 below with the candidates *plebis* and *superare* (corresponding to the two variant readings *plebis iudeorum* vs. *plebeiorum* and *uel superare* vs. nil). If the both are true *leitfehler*, one of the four combinations cannot occur. The archetype reading could be any of the three remaining combinations, depending on the phylogenetic connection of the two errors. Assessing all such pairings, we assume that the best *leitfehler* will contribute to the largest number of pairings that are "consistent" in the sense that the manuscript corpus has exactly three out of four possible combinations. In order to avoid everyday words we did not include words of 4 letters or less. This information can be fed into the metric, giving any edit that includes one of the identified "good *leitfehler*" a significantly higher score.

	nothing	*uel superare*
plebeiorum	Br, P2, P4, Zu	A2, A3, An, Au, B2, Be1, Be2, Ca, Cc, Cp, Do, Fi, Go, Gy, Ha, He, J1, Kn1, Kn2, L2, L3, Ld, Li, Mu, Ob, Or, P1, P5, Pr1, Sa, T2, Ut, V2, Wi
plebis iudeorum	B1, Bo, Cr, D1, D2, Kr, L4, Me, P7, Po, Pr3, T1, Ta, To	–

Table 3: Two of the most promising leitfehler in our text sample combined. The combination plebis iudeorum and uel superare exists in no ms.

37 *Leitfehler* may be differentiated into *trennfehler* and *bindefehler,* separating and linking respectively mss.

Testing with an artificial tradition

Baret et al.[38] have tested various methods on an artificially produced tradition comprising twelve manuscripts that were copied by different people from one another in a rather complicated manner (including a case of contamination). Various groups of biologists used their programs to reconstruct a stemma, and most of their results were quite good, even though the best result was reached by classical, manual stemmatology. The authors see this as due to the limited size of their tradition and believe automated approaches to be of special value "with large textual traditions and different scholars working in partnership to provide new transcripts and collations." Baret et al. had a French text of some 1000 words transcribed by different people. We used their data[39] to gauge our diff algorithm. Fig. 1 compares our result, a selected "good" result[40] from Baret et al. and the true stemma. The ms. Ω was "lost", i.e. its data was not available for analysis. On the whole our result compares with the best artificially generated ones in Baret et al. The main flaws in our stemma are (a) the hyparchetypes A and U are placed too far off their parent nodes (in the case of U, this distance is sensitively dependent on the parameter *p* due to the specifics of the errors of that particular scribe) and (b) the algorithm was inherently unable to detect the contamination in F.

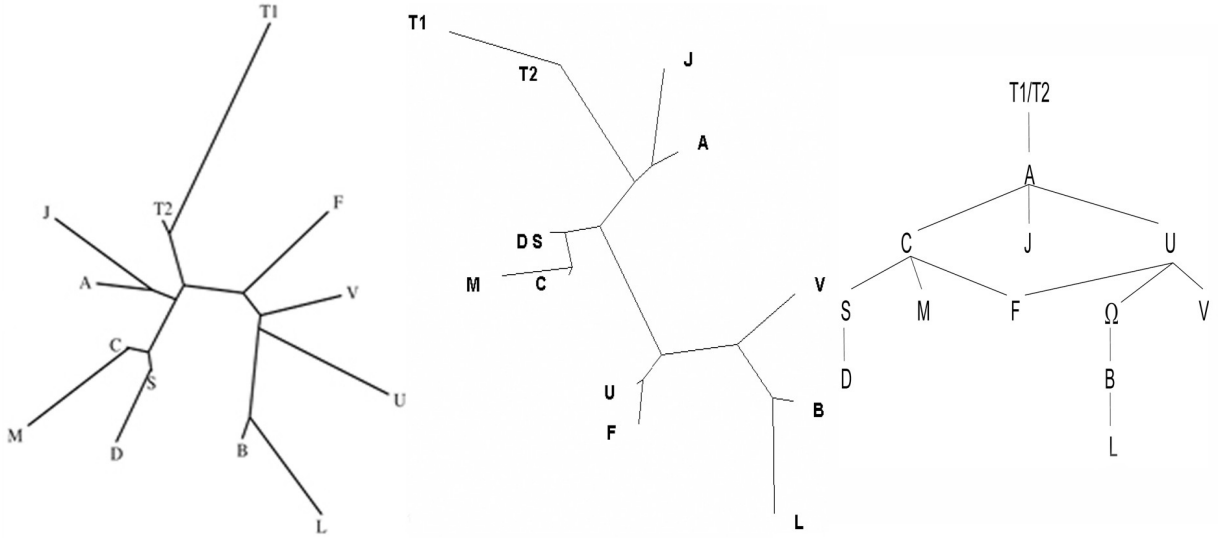

Fig. 1 Artificially created manuscript tradition. Comparison of our result with the diff algorithm and a coefficient of p=0.5 (left), one of the best results in Baret et al. (middle) and the true stemma (right). Neither of the generated trees is rooted.

Results for the *Dialogus*

In the following, we present the automatically generated trees for the 51 complete mss of the *Dialogus* text sample, using the approach detailed above. All trees are generated from their distance matrices using the Fitch-Margoliash method. Fig. 2 shows the simple approach of counting edits reported by "diff", consecutive edits weighed with the exponent of p=1/2 as discussed above. Fig. 3 additionally uses the 25 best *leitfehler* candidates identified automatically.[41] The contribution of edits involving one of these 25 words to the distance function was set at 30 times the contribution of a regular edit. The resulting graph has a more articulated structure, setting the phylogenetic groups identified more pronouncedly apart from the symmetric star-shape of a "null solution" graph. The main flaw in this tree is the crowded double group in the middle to the left, basically group E (see below), but adding also T2 and P2.

38 Ph. Baret, C. Macé, P. Robinson, *Testing methods on an artificially created textual tradition,* in *The Evolution of Texts (op. cit.*), p. 255-283. The quote from p. 280.

39 Many thanks to Caroline Macé for the digital text!

40 Obtained by the Neighbour Joining method, cf. *op. cit.* p. 270.

41 For our text samples these were (in order of their automatically calculated goodness): *plebis, plebeiorum, effectu, expositor, propter, prophetiarum, relatorem, recte, fuisset, cognosceres, recipimus, iudeorum, elatorem, delegissem, effectum, adheserat, scriptis, peruenit, rectam, recepimus, compositor, superare, coequeuos, uirili, scripturis.*

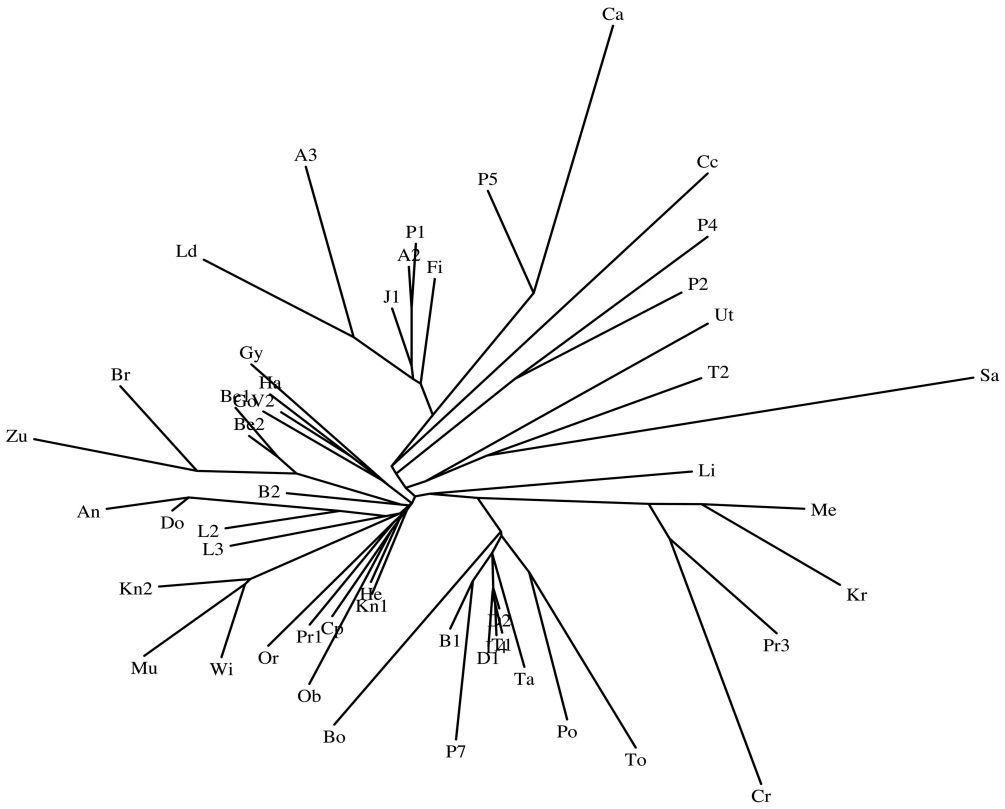

Fig. 2 Tree graph using a simple *diff* algorithm, again with a coefficient p=0.5, for our 51 complete mss. The branch length between any two mss is calculated to approximate their distance in the present metric.

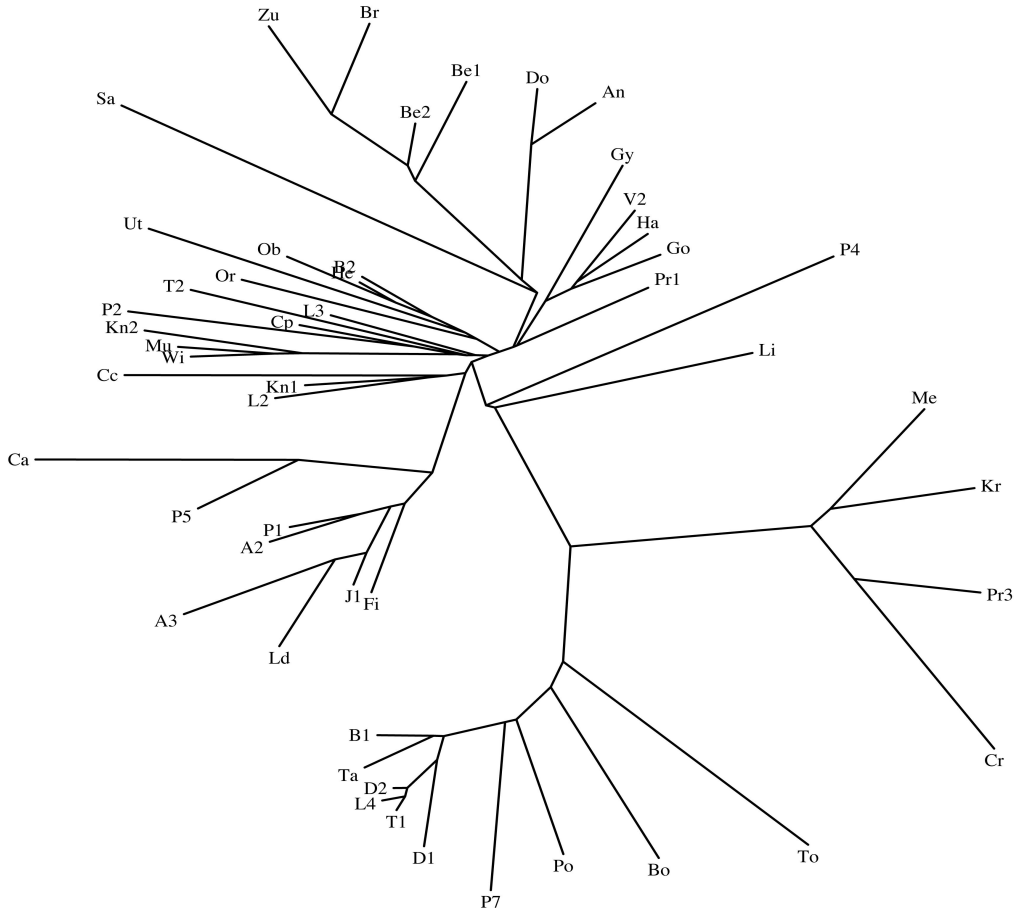

Fig. 3 The same graph improved with a list of 25 automatically found *leitfehler*.

(v) manually improving the list of leitfehler

Since we have developed a method of generating a tree largely determined by a given list of significant variant readings or *leitfehler*, there is nothing to stop us from reviewing the *leitfehler* candidates manually and redrawing the stemma based on a hand-picked list of words that we consider significant in this sense. It should be noted that at this point, we depart from the goal of a stemma that is generated in a fully automatised way, as it were at the push of a button. In the following, we present much rather our best guess at the stemma based on a happy marriage of our human philological judgement with the computing power of our algorithm. In fig. 4, we show the tree generated in the same manner as fig. 3, but based on a list of 22 *leitfehler* we selected manually from the suggested candidates. For this we removed cases like *effectu* (vs. *effectum*; the two often hardly distinguishable in the mss) of *fuisset* (vs. *esset*, which could easily replace it) and added a few short but good ones (like *uie* vs *me*). As the two readings of a single *leitfehler* can in any pairing of two ms. only once be different, it does not matter whether we include one or two readings of the pair[42] The improved result is shown in fig. 4.

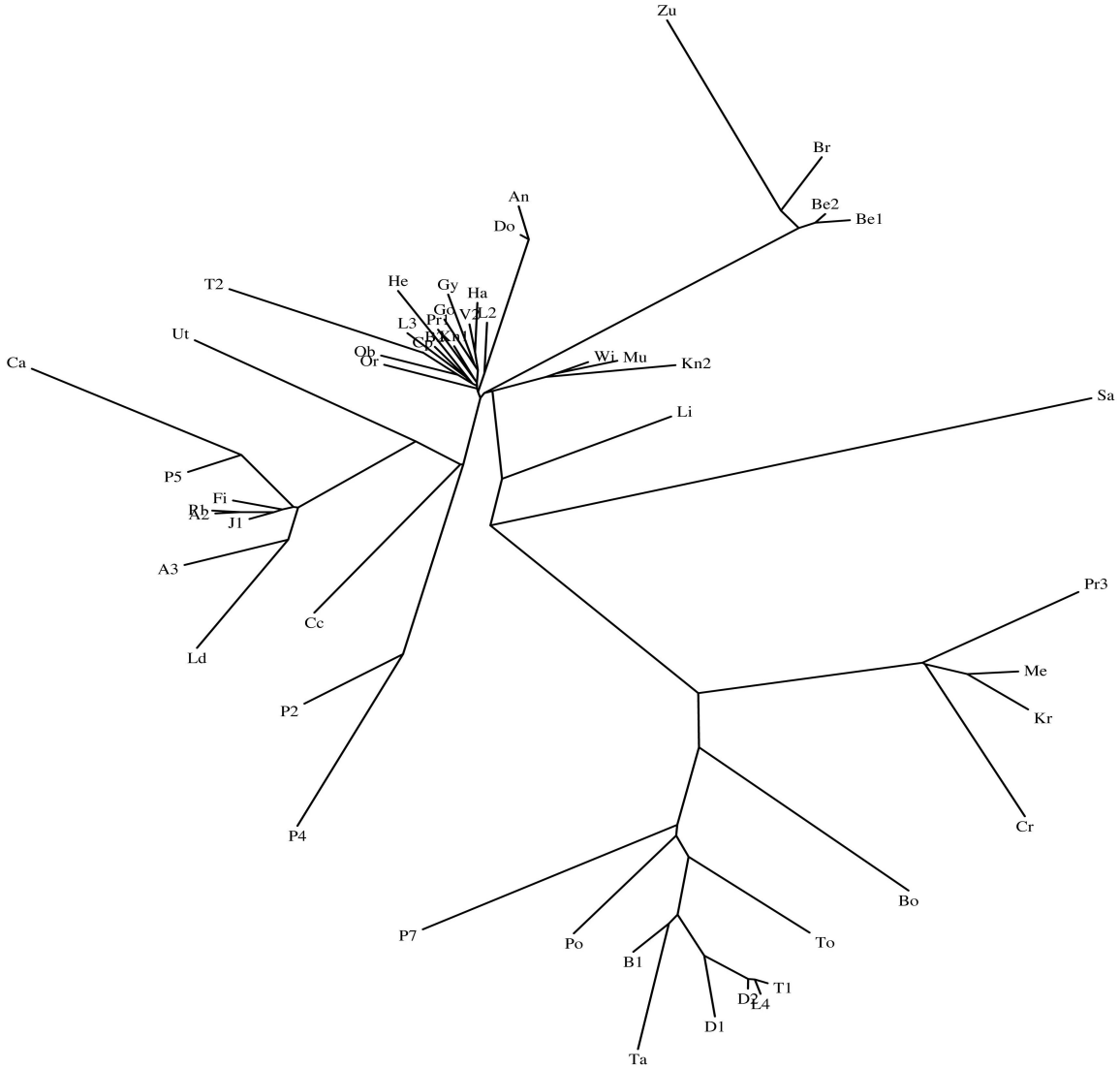

Fig. 4 The same graph with a manually improved list of *leitfehler*. The main groups are much more clearly separated now.

42 Using our philological knowledge about the tradition we changed the list to: *plebis/ iudeorum/ plebeiorum, compositor/ expositor, relatorem/ elatorem, genuit/ peperit, intueor/ uideo, aduersionis/ defensionis, recte/ rectam, uie, propter, aduenire, perpendimus, adheserat, delegeris, uirili.* Where the corresponding word occurred often in the text (like *me* corresponding to *uie*) it could not be used. These *leitfehler* largely correspond to table 4, without making use of the 14 *leitfehler* from outside our text sample.

Philological analysis

Manually improving the automatically detected *leitfehler* list used for fig. 3, we arrived at a more reliable stemma shown in fig. 4. As this data still seemed unable to differentiate what will be groups B and E at the centre of the plot, we chose to compare another 14 promising *leitfehler* we found outside our text sample in a more technical section of the *Dialogus* (between Mieth 10,39 and 13,6).[43] This new data we appended to our previous excerpts and obtained the improved plot in fig. 5. The new data was indeed capable of resolving the big cluster of mss in the centre into groups E and B. So fig. 5 uses information from the *Dialogus* in addition to the 520 word text sample we had excerpted, as indeed our text sample seems to have been somewhat short.

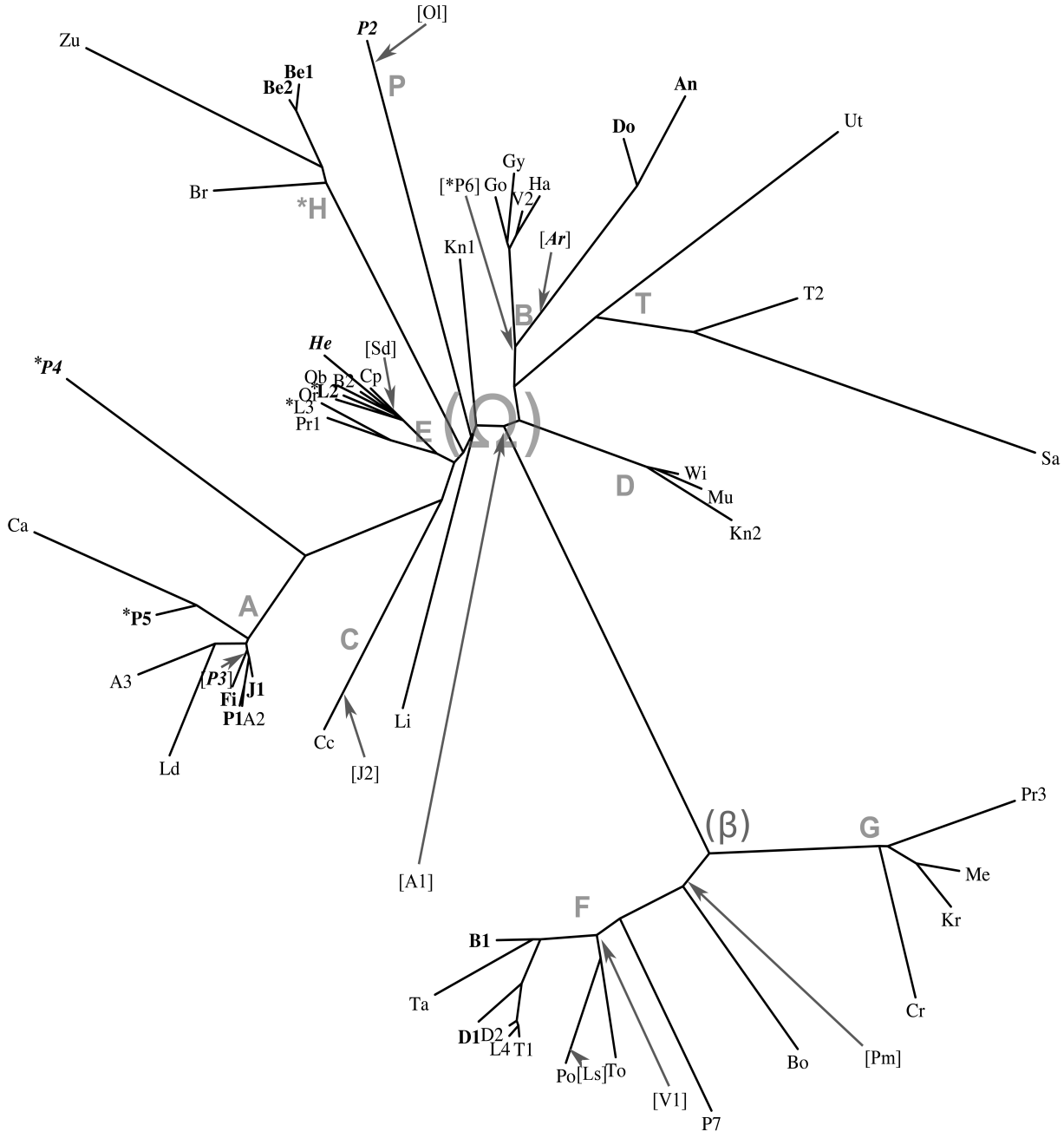

Fig. 5 The same graph further improved by 14 more *leitfehler* from outside our text samples. Additionally inserted into this plot are the approximate positions of the incomplete mss (marked with arrows). Mss still from the twelfth century are highlighted in bold-face, those probably even from its first half in bold and italics. Our proposed groups (cf. fig. 6) are added in grey capital letters.

43 We thank Darko Senekovic for helping us search the mss for these readings.

In order to classify the ten mss that did not contain all our sample text and were therefore excluded above, we plotted the tree graph for only that part of our text sample which was contained in any of the missing mss with all the complete mss. These plots, except for V1 where about half our sample text is missing, yielded plots very similar to fig. 5. In order to save space we chose not to include these plots but instead manually integrate the incomplete mss into fig. 5 at the approximate position they occupied in the partial plots. These insertions are indicated by grey arrows and the incomplete mss are additionally marked by brackets. As the different plots show, the resolution of our method is not good enough to yield much detail about the dependencies at the central cluster of nodes (where ideally the position of the archetype Ω should be resolved alongside early hyparchetypes). While hyparchetype β is clearly articulated (marked in fig. 5), hyparchetype α, which we will postulate below, close to Ω linking β with groups P and (partly) H, is not discernible at all. The oldest mss (bold and in italics in fig. 5) are scattered over a large part of the plot indicating the quick differentiation of the manuscript tradition.

Combining fig. 5 with a manual study of the mss,[44] resulting in a list of *trennfehler* (separating variants) between the groups, presented in table 4, we can propose a reliably confident stemma of the tradition (drawn in fig. 6). The vertical boxes contain the individual manuscripts in each group, aligned chronologically. In cases where we were confident of direct descent we marked it with a line (horizontally where the direction seemed unclear). Probably contaminated mss are marked by an asterisk and dotted lines.

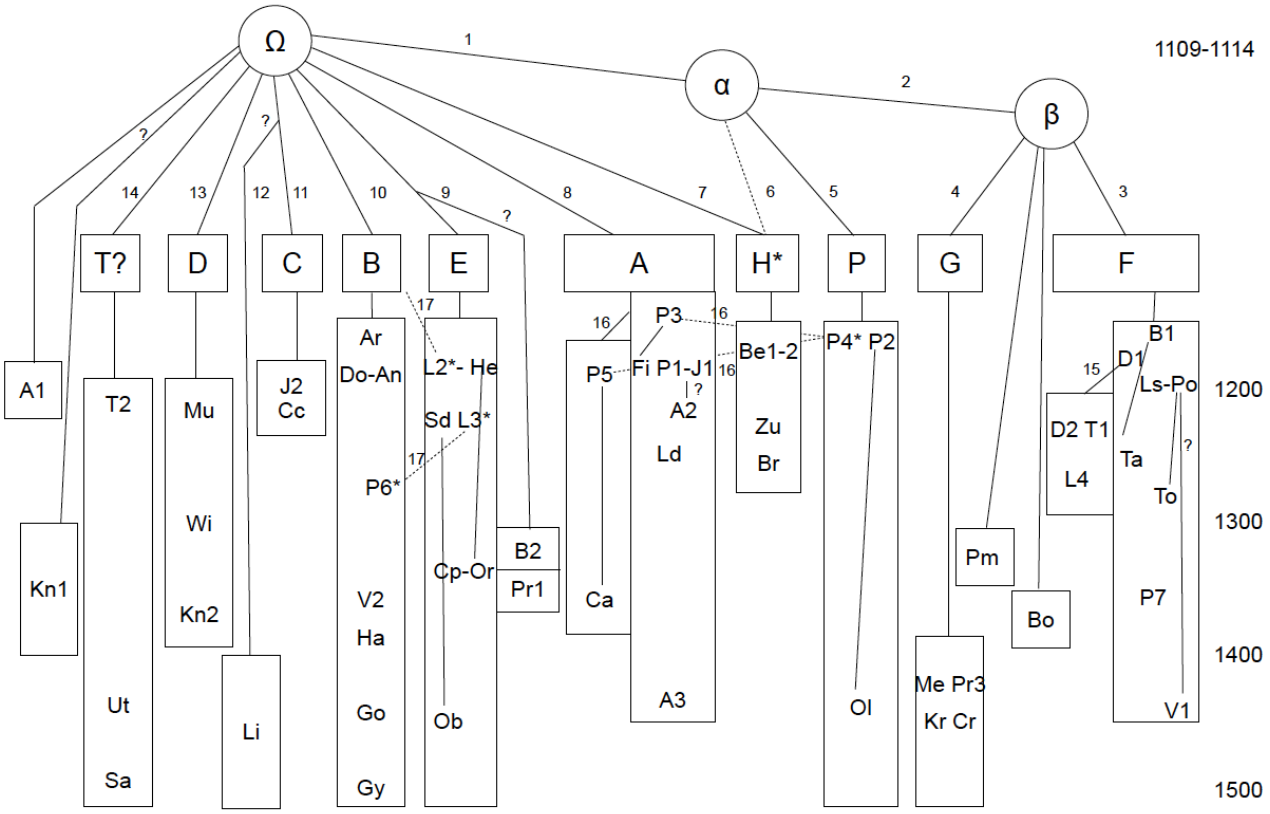

Fig. 6: The final *stemma codicum* we propose for the *Dialogus*. Ω represents the archetype, α and β early hyparchetypes, the boxes below contain group symbols, introduced for ease of reference; they are not meant to necessarily represent a single (lost) manuscript each. The numbers refer to the *leitfehler* listed in table 4.

44 Such a manual study of a large number of mss is facilitated by the freeware application Juxta (http://www.juxtasoftware.org/).

No.	*errores significativi*	other mss?	comments
1	*similiter gradus qui est in occidente sole in Aren occumbente, non est idem cum eo qui eadem hora alii apparet civitati* missing [Mieth 10,31-32] *uel superare* missing [143,16]	H has it not in Be1, Be2	contamination H is contaminated, cf. 6/7
2	*me ad* not *ad uie* [1,11] *propter* not *per* [3,24] *plebis iudeorum* not *plebeiorum* [3,34] *cotidie* not *assidue* [10,40] etc.	- - - -	many differences; β is clearly secondary
3	*expositor* not *compositor* [1,10] *elatorem* not *relatorem* [3,28] [a subgroup has *latorem*: Ls, Po, To, V1]	- -	*auctor*: Pm; Ls, Po, Bo passage missing *emulatorem*: A1 & D1 (*elatorem* a.c.)
4	added *descendit ad inferos* [1,26] *elegissem* not *delegissem* [3,17] *aduenire* not *ad te uenire* [3,21] *propter quam* not *propter quid* [3,24]	- also Kn1 also P also Li, Kn2	Pr3: *d* sub ras.
5	*genuit* not *peperit* [1,20] *aduenire* not *ad te uenire* [3,21]	- also G	both incl. P4*
6 & 7	*aduersionis* not *defensionis* [3,28] *similiter gradus qui est in occidente sole in Aren occumbente, non est idem cum eo qui eadem hora alii apparet civitati* extant [10,31-32]	- -	in H only in H (with Ω) though missing in α
8	*uiri* not *uirili* [1,20] *delegeram* not *delegissem* [3,17] *intueor* not *uideo* [3,23]	also F’ - -	excl. P4* incl. P4* incl. P4*
9	*accurrit* not *peruenit* [3,18]	also P2, Mu (cf. 13)	B2 and Pr1 do not have this reading, but are otherwise closely related to E
10	*supradicta* missing [12,33] *agnosceres* not *cognosceres* [143,21]	 Au, Br, Ls	*predicta:* P2 and maybe Ol (data missing) P6 passage missing
11	*qui a primeua etate meus consocius fuerat condiscipulus* missing [3,15-16] *cur* not *per quam* [3,24]	- -	
12	*abducens* not *educens* [11,28] etc.	-	Li differs from all other groups, it seems to be most closely related to C
13	*uenit* not *peruenit* [3,18] *existimatione* not *estimatione* [3,32]	not Mu also An, Do, P4*	Mu has *aduenit* (*accurrit* a.c.); both are not very good errors
14	*delegeris* missing [3,25]	-	uncertain group
15	*uiri* not *uirili* [1,20]	also A (not P4*)	incl. D1, F’ seem to be copies of it
16	cf. 5 and 8		

17	P6* often has readings from E and is contaminated; most likely by L3. Equally L2* contains readings from B		

Table 4: The best *leitfehler* for each grouping found in our text passages. The numbers correspond to the *stemma codicum* in fig. 6.

Let us now summarise what we know about the groups visible in the stemma (fig. 6). Suspected direct copies are marked with an arrow, cases of probable contamination with an asterisk.

Group A ("Anglo-Norman"[45]): P3 → Fi, → P5* → Ca; P1–[46]J1 → A2, A3, Ld; (P4)*. This group is based on the Anglo-Norman ms. P3 from the Benedictine abbey Fécamp in Normandy. P4, of unknown provenance, is contaminated between groups P and A, there probably descending directly from P3. In our plots it fluctuates between these two groups. It may have been occasionally used in turn in the writing of P5 (based on P3) which has a rather erroneous descendent in Ca (together "A'"). Among the rest of the group P1, J1 and A2 are more closely related. Fi seems to be faithfully copied from P3. The later A3 and especially Ld are less faithful copies belonging to this group.

Group B ("Belgian"): Ar; Do → An; V2, Ha, Go, Gy; P6*. The three oldest mss of the group are from the French-Belgian border region. The oldest and best ms. of the group would be Ar which, unfortunately, lacks pages. Do seems to be slightly older than An, so An is likely a copy of it. The two mss are closely related and have many additional mistakes in common, so due to the contamination in L2 (and possibly L3) in our less sophisticated plots these two mss fluctuated between groups E and B. V2, Ha, and Go are German (as far back as there provenance is traceable), therefore it seems likely that the ms. the *editio princeps* Gy was based on came from Corvey in Germany not from Corbie.[47] P6 is contaminated by group E (perhaps L3), besides being incomplete and containing many mistakes of its own.

Group C ("Cambridge"): J2, Cc. The two mss in this group are now in Cambridge. They share some omissions and do not seem to have a very good text. Li, which does not fit in any of the groups, has some readings in common with C and may be considered a distant relative of the group.

Group D ("Danubian"): Mu, Kn2, Wi. The three mss in this group stem from the Danube region. We have found no very convincing *leitfehler* for them, but the bulk of the ones we have still make for a clear-cut grouping.

Group E ("English"): He → Cp → Or; →? L2*, L3*; Sd → Ob. This mostly English group is in many respects the most complicated one; its mss differ in few *leitfehler* and thus tend to get clogged together at the centre of our plots. The old ms. He has two probable descendants in Cp (a bad copy) and Or. L2 has a layout virtually identical to that of He; it is likely to be a copy of it, probably contaminated by group B. L3 (a bad copy) may also be contaminated by group B (or L2) and in turn seems to have contaminated P6*. Sd, which has curiously found its way to Spain (Santo Domingo de la Calzada), has a descendent in Ob (they share the unique *gremio* instead of *cunis* [Mieth 3,37]). B2 (more closely) and Pr1 seem to be related to group E though they do not share its most distinctive reading.

Group T ("Troyes"): T2, Sa; Ut. This group with its oldest ms. from Troyes is not well defined. But its three mss do seem to be related. All of them are quite far from the centre of our plots. Curiously the diff-plot (fig. 2) is able to resolve this group unlike plots 3 and 4; plot 5 finally resolves them quite clearly. Sa was prepared for printing by a humanist, apparently from a lost ms. The editor smoothed the text significantly.

45 These names are meant to be mainly mnemonic.
46 P1 and J1 are closely related and roughly of the same age. Probably one is a copy of the other.
47 Cf. above note 20.

On hyparchetype α[48] depend two groups and another hyparchetype, β.

Group H* ("Helvetic"): Be1 → Be2; Zu, Br. The entire group is contaminated. The Bern mss often differ from the other two which are mostly in accord among themselves.

Group P ("Parisian"): P2 → Ol, P4*. P2 and its late copy Ol contain many special readings, some of which are shared by the contaminated P4 (cf. group A).

Hyparchetype β has usually inferior readings.[49]

Group F ("French"): B1 →? Ta, D1 → (T1, D2, L4), Ls → Po →? V1 and To, P7. This big group's most ancient mss are French, many of its descendants, however, are found on the Iberian peninsula. Most of the mss were written in Cistercian abbeys; apparently they moved among Cistercians from France to Spain and Portugal. Ta seems to be quite a bad copy of B1; T1, D2 and L4 copies of D1 thus forming a subgroup (F'). Ls, Po (these two very closely related, Ls apparently a little older), To and V1 lacking pages[50] share the reading *latorem* [Mieth 3,28], suggesting another subgroup. The two mss Bo and Pm depend on hyparchetype β, possibly being direct copies of it, but not to one of the two groups here described. Pm is incomplete and contains a lot of mistakes.

Group G ("German"): Me, Cr, Kr, Pr3. This mostly German group is the only one comprising only late mss. Nonetheless, as they share a number of readings, they will all go back to a lost copy of β. Me and Kr seem to be copied by the same scribe. Cr is a bad copy.

Manuscripts that do not belong to any of the groups above, besides the mentioned B2, Pr1 (related to E) and Li (to C), are: A1 (incomplete), Kn1 (both quite different from all the rest) and Au, which has changed the text so much that it is not possible anymore to determine where it belongs to.[51]

In conclusion, we were able to determine different groups of manuscript traditions of the *Dialogus*. The following manuscripts are the most important ones in their groups. A: P3 (where incomplete Fi) – B: Ar (where incomplete Ha or Go) – C: does not contain good mss (the related Li being the most interesting) – D: Mu – E: He (and possibly B2, Pr1) – T: T2 – A1 seems interesting though incomplete, Kn1 should also be considered for a critical edition – dependent on hyparchetype α, Be1, maybe Zu and P2 ought to comprise the whole range of readings – among the secondary hyparchetye β B1 is the oldest and most important ms., Bo and Me also seem interesting.

Unresolved Issues

We have compared stemmatology in philology to phylogenetics in biology. This parallelism is not original to us, nor is it recent: it was developed in the 19th century, the golden age of philology, as evident from the metaphor of genealogy in *stemma,* or *stammbaum*, which together with the *stamm-baumtheorie* in historical linguistics reflect the desire to reproduce the rigour of Darwin's *Origin of Species* of 1859 in the humanities. Nevertheless, there are a number of significant differences between the tradition of a text and biological evolution. These differences are mostly a matter of scale, as in the length of the "text" being transmitted, the number of generations and the number of extant individuals available for analysis. There are also more fundamental differences, which we shall now briefly discuss.

One problem not addressed by our algorithm is the localisation of the (lost) archetype within the stemma. This is the problem of "rooting" the tree diagram. In practice, a "vertex" in the diagram where many lines converge[52] will likely be the archetype, or at least an important hyparchetype. But

48 Its existence can be deduced from the two *leitfehler* in table 4, position 1.

49 Therefore Mieth's decision to use one of its mss (B1) as his main source was unfortunate.

50 Among V1's missing text is unfortunately our entire text sample 2. Thus the ms. could not be well positioned automatically in the tree.

51 This bad and highly idiosyncratic ms. has been omitted from the plots because its very long branch would have used a lot of space and not provided additional information.

52 Strictly speaking, a cluster of nodes in close proximity, as in our tree-diagrams each node connects exactly 3 lines.

note that in the case of two major vertices, as seen in Ω and β in fig. 5, there is no indication of whether the vertex at β descends from Ω (as we suggest), or vice versa. In order to determine this, a notion of directionality needs to be introduced. In biology, this can be done from a distantly related "out-group". For a text that was written (i.e. created so to speak *ex nihilo)* at a certain point in time, this method is not available.[53] Traditionally several methods based on *leitfehler* together with a good deal of intuition are used in ways that do not lend themselves to algorithmic description.

A second, even more severe problem for manuscript stemmata are contaminations. Unlike the biological agents that replicate DNA, manuscripts are copied by thinking scribes, who may produce errors that are not distributed randomly. In particular, a scribe may have more than one manuscript from which to create his copy, and may use his own judgement in cases where his originals disagree. The result is a stemma that is not tree-like, containing nodes with more than one parent node. A somewhat comparable effect in biology would be the so-called horizontal gene-transfer especially common among bacteria. There does not seem to be any established way of dealing with the problem among biologists. Pseudo-nodes, allowing more than three branches to branch off, could be introduced to simulate this problem. They have to be heavily penalised in the algorithm in order to avoid that the algorithm uses them to find easy fits. Recently, Makarenkov et al.[54] have attempted to implement such an approach. Their idea is to calculate a true tree which is then gradually improved by adding pseudo-nodes. Applying such approaches to manuscript traditions is beyond our present scope.

A third, and somewhat prosaic issue is that of uncertain readings and lacunae in damaged mss. Such flaws in the excerpted text will tend to deteriorate the quality of the database. In general, the solution will be a pragmatic emendation in places where the reading does not differ significantly across mss. In the case of mss that lack significant portions of the excerpted passage, the incomplete mss can be omitted in a first step, and fitted to the generated stemma in a second step, as we have done above.

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53 A possible parallel to the "out-group" approach would be quotations from a work not readily available to the scribe (unlike the Bible) but whose original text is known. In our case the direct translations from the Qur'an or the Talmud that Petrus Alfonsi makes might be used as an out-group as both texts were virtually unknown in the Latin West. However, due to problems of translation and the absence of critical editions of the source texts this idea is beyond our present scope.

54 Cf. V. Makarenkov, P. Legendre, *From a phylogenetic tree to a reticulate network,* in *Journal of Computational Biology,* vol. 11 (2004), p. 195-212, and the online tool: http://www.labunix.uqam.ca/~makarenv/trex.html.